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User satisfaction adaptive behaviors for assessing energy efficient building indoor cooling and lighting environment

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A B S T R A C T

Many techniques for managing sustainability including sustainable building assessment tools and standards have been developed globally. The sustainable building assessment tools measure the user satisfaction dependent to environmental and economic aspects of energy efficient building practices. However, these tools have not yet measure energy efficiency index by involving user satisfaction from adaptive behaviors dependently, which can determine the actual energy consumption versus the planed energy consumption of the building. Hence, this research aimed at providing a comprehensive list of adaptive behaviors for assessing energy efficient building indoor environment in design phase of building lifecycle. The study focused on identifying and establishing adaptive behaviors that are in response to indoor conditions provided by Cooling and Lighting systems in energy efficient office buildings. This research involves adaptations across Technological and Personal. The research was conducted in two phases. Phase one identified the list of user satisfaction adaptive behaviors through a systematic approach. Next, an expert input study was conducted to validate the findings of the literature review. Expert input data was collected using Delphi structured close group discussion method, and then analyzed through Grounded Group Decision Making (GGDM) method. Eight experts were involved in four sessions of the GGDM application procedure. The research established 18 adaptive behaviors relevant to cooling system in energy efficient indoor environments, and 18 adaptive behaviors relevant to the lighting system. The comprehensive list of user satisfaction adaptive behaviors can be applied in both current and future sustainable building assessment tools' energy efficiency indexes. This aids architects, engineers, facility managers, building owners, consultants, authorities, contractors, and academic researchers in accreditation of building users, building design and reduction of building's energy consumption.

Contents

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1. Introduction on sustainable building assessment tools

There are efforts to manage the implementation of sustainability methods and techniques in building practices. This is carried out with the aid of four sustainability methods and techniques; viz. (a) governmental status, (b) building codes, (c) private and professional associations or Non-Governmental Organizations (NGOs), and (d) marketing strategies [1]. Amongst, the largest contributor to enhance sustainability in building practices is the private and professional associations, NGOs [1]. NGOs have mainly resulted with multi-perspective 'Building assessment tools' to enhance sustainability of building practices in specific regional areas [2,3].

In the building constructions industry, assessment tools are specifically used to benchmark enhancement of sustainability in building practices [4]. Using assessment tools is a contribution of 'Managing Sustainability' to the building construction industry. These tools traditionally called 'environmental building assessment tools', 'green building assessment tools' and recently called 'sustainable building assessment tools'.

Building assessment tools are mainly aimed to benchmark a 'Capacity Building' as a sustainable building case (i.e. social, economic, and environmental building) in a specific geographic region. It includes existing buildings as well as new buildings across diverse functionalities, such as, office buildings, residential buildings, commercial buildings, etc. [5]. These tools involve a variety of features for sustainability assessment including, energy efficiency, water management, waste management, land use etc. [1]. Basically, these features cover the greenery/environmental issues, with consideration on economic and social-friendly approaches. To improve usability of tools with building lifecycle, it may benchmark building's 'sustainability' in design phase, construction phase, operational phase, and/or demolition phase [5]. According to Haapio and Viitaniemi [5] tools' end-users would be architects, engineers, facility managers, building owners, consultants, authorities, contractors, and/or academic researchers. The academic researchers indirectly use the sustainable building assessment tools as decision support tools in order to fulfill the requirement of building sustainability accreditation [6].

There are some efforts being undertaken to establish standardized requirements for building assessment tools. International Organization for Standardization (ISO) [7,8] investigated assessment features to develop harmonized basis to measure the sustainability of the subject matter. The ASHRAE-55 standard [9] measures the correlation of indoor thermal environmental parameters (temperature, thermal radiation, humidity, and air speed) and user parameters (clothing insulation and metabolism rate). Using ASHRAE-55 standard [9] aids building energy managers to provide thermal environmental conditions acceptable to a majority of the users [10] The EN15251 standard [11] established environmental input parameters for design and energy performance calculations within non-industrial buildings, such as, office buildings [10]. Recently, Temperature Limits guideline (ATG) was developed as an alternative to the Weighted Temperature Exceeding Hours method (GTO). The ATG has the flexibility to predict various types of buildings including naturally ventilated buildings, and the mechanically conditioned buildings with sealed facades [10]. Also, the Construction Related Sustainability Indicators Project (CRISP) is a thematic network on construction and city related sustainable indicators which have been introduced based on the review of all existing tools.

2. Gap in sustainable building assessment tools

Since early 1990s, about sixty 'sustainable building assessment tools' have been established by private professional associations, or NGOs all over the world, such as, Building Research Establishment Environmental Assessment Method (BREEAM), Hong Kong Building Environmental Assessment Method-HK-BEAM [12], Leadership in Energy & Environmental Design-LEED [13], Sustainable Building tool [14], Singapore Green Mark Scheme [15], and Green Building Index-GBI [16].

With regards to problems with sustainable building assessment tools, there are some shortcomings addressed by researchers in the available literature. Gibson [17] stated that the established tools do not work effectively towards sustainability. Abdalla et al. [6] mentioned that the sustainable building assessment tools do not consider end-user sustainable program. Furthermore, Pemsel et al. [18] express that lack of 'guidance and narrow focus' restricts the ability of tools in the assessment process. Moreover, there is always a deficiency in using any 'global standardized' assessment tools [4].

According to literature, majority of building assessment tools lack focusing on energy and environment aspects in the design phase of building life cycle. Lützkendorf and Lorenze [19] stated "… due to the complexity involved, only a few tools, such as, LEGEP [20] and OGIP [21] exist that allow for a combined determination and assessment of cost, environment and to some extent occupational health and other social issues in the planning phase". Christensen [4] stated that 'user satisfaction' and 'development impact on community' as social sustainability criteria need to be considered in sustainable building assessment tools.

Lützkendorf and Lorenz [22] stated that assessing a building's contribution to sustainable development requires an integrated building performance approach. This allows one to describe and assess buildings with respect to all dimensions of sustainable development including aspects of functionality and serviceability as well as the quality of planning, construction and management

process. Lützkendorf and Lorenz [22] proposed assessment tools to influence the design of buildings that will allow architects and engineers to use them to compare different solutions or optimize sketches and designs during the whole design process, including the very early phases of conception or pre-design. Besides, Chen et al. [23] indicated that another problem of current building assessment tools is their calculation process are not convincing enough to provide a reasonable assessment results in energy consumption and energy savings within design phase of building life cycle.

Zhun et al. [24] listed seven different sources that can affect energy consumption of a building; including, (1) Climate, (2) Building-related characteristics, (3) User-related characteristics, except for social and economic factors, (4) Building services systems and operation, (5) Building occupants' behaviors and activities, (6) Social and economic factors, and (7) Indoor environmental quality. The sustainable building assessment tools have neglected to consider building occupants' behaviors and activities [25], and in particular, occupant satisfaction. Sustainable building assessment tools covered the user satisfaction in correlation with Indoor Environmental Quality (IEQ) by following the standards of energy efficient building (for example; MS1525) [26], or, using Post-Occupancy Evaluation (POE) methods.

The user satisfaction has been studied across disciplines; such as, building architectural design, building value management [27], building asset management [19], real estate management [19], and construction management. Reviewed literature revealed that the user satisfaction has been analyzed based on environmental and economic aspects of sustainable building practices [28]. SBtool is the building assessment tool lunched to consider the 'user satisfaction' as an independent criterion in the building assessment index. The user satisfaction in the SBtool seeks to analyze its 'inter-connectivity' with other sustainability criteria.

In sustainable building assessment tools, the user satisfaction criterion can be inter-connected with energy efficiency. As an example, if the level of user satisfaction in compliance with energy efficient lightening is low, the user will cause the building asset to the satisfactory level. But, the satisfaction level may not fulfill economic and/or energy performance levels. According to Zhun et al. [24], among diverse types of 'building occupants' behaviors and activities', the 'adaptive behavior' is a measure of user satisfaction which may enhance energy programs [29–33]. This confirms the need to enhance sustainable building assessment tools in consideration with the user satisfaction from 'adaptive behavior' as a missing criterion.

3. User adaptive behavior and activities affecting energy consumption of building

Yang et al. [32] opined that "people are not passive recipients of their immediate environment, but constantly interacting with and adapting to it". Indeed, some changes in indoor environment cause discomfort and dissatisfaction of building users and persuades them to adaptation activities in physiological, behavioral and psychological aspects [33]. O'Brien and Burak Gunay [34] stated that most of adaptive behavior models integrate current environment state to predict desirable adaptive conditions. But, the adaptive behaviors of office user can be captured as follows [34]: (1) users decide to react based on the current conditions causing discomfort and, (2) users anticipate future discomfort and based on their previous experience, and then, choose the adaptive states accordingly. The observational studies proved that occupants adapt to the building indoor conditions as they desire and satisfy with them. Fabi et al. [35] and Herkel et al. [36] stated that the users adaptation can be due to, (1) they are exposed to a sharp gradient between indoor and outdoor conditions; and (2) the ease of accessibility to controls as they walk in.

Chung [37], Roetzel et al. [38], and Yun and Steemers [39] stated that 'building occupants' (i.e. users') behaviors and activities' is the most common factor causing fluctuation in actual energy consumption versus the planed energy consumption. Jackson [40] in his review paper stated that previous studies developed various models or simulation programs to measure and predict users' different energy consumption behavioral patterns. Studies on user behavior and interaction with building systems for energy consumption have increased the knowledge and understanding of building performance [41].

Eang [42] defined 'tenant' and 'land lord's energy consumption features'. The landlord's consumption includes all the energy consumption happening in common area, for cooling lighting or any other purpose. Land lord energy consumption features are less depend on tenancy rate and building users commonly do not have a control over these features. The tenants' consumptions are mainly in the areas where energy consumption depends on tenancy rate and tenant's behavior. Tenants' consumptions include energy consumption from

- lighting systems,
- cooling systems,
- building facilities (e.g. elevator),
- working equipment (e.g. printers, and computers).

As a consequence, while these advancements are compelling, recognizing users' attitude and self-sufficient lifestyle [43] and 'Voluntary Simplicity' approaches [44] which have potentially great implications for energy consuming remain as critical challenges. Adaptive behavior might be in a form of having energy saving life style, while based on Sorrell et al. [45] might result in bad consumption habits known as the 'rebound effect'. Jackson [40] indicated that 'green' social marketing campaigns or financial incentives can avoid such rebound effects. Azar and Menassa [46] and Allsop et al. [47] addressed 'word of mouth' effect, which is considered to be a very influential channel of green communication which was investigated by Harrison-Walker [48]. Review of literature on field studies and simulation of building users' adaptive behaviors confirmed that different type of awareness can significantly influence building energy use [49,28,31].

Cole et al. [2] reported a manifesto by Passive and Low Energy Architecture – PLEA [50] conference. They stated that with the aim of highlighting building user as key component of energy efficient program this manifesto was prepared. The manifesto highlights the necessity to

- raise 'social and ethical challenge' in building energy efficiency program; and
- consider 'dynamic and responsible' involvement of user and designer at architecture design phase of building project.

Andersen et al. [51] defined 'user's control' as effective factor for indoor environment. They suggested the use of total central control system to minimize the influence of occupant behavior on the performance of the building since only central cooling control system was not found effective. Maaijen et al. [52] express that it is needed to deploy energy effectively for comfort on those spots where needed. Jazizadeh et al. [53] express that thermal comfort is "a condition of mind, which expresses satisfaction with the thermal environment and is therefore, subjective". Thermal comfort is intensely related to the body thermal balance that itself is affected by environmental and personal parameters [54]. Zhao et al. [55] indicate that knowing per user's thermal comfort preferences and comfortable level, can aid designers and facility

managers to control building indoor environment based on single user's setting and/or settings in a controllable micro-environment. To achieve this conveniently, it is necessary the Heating, Ventilation, and Air Conditioning (HVAC) systems automatically adapt to the actual individual needs. In this regard, Maaijen et al. [52] proposed a method where the user with his individual needs is included in the control loop, which was called 'human in the loop approach'. Through this approach up to 40% energy savings can be achieved on cooling demand compared with the actual energy demand [52].

Furthermore, the building simulation studies understood association between users' adaptive behavior and building energy consumption. In this discipline, the effort is to predict the user's behavior for better design performance. Recently, there is a trend towards activity-based modeling on human behavior simulation. There are few models established by researchers [49,56–61]. For example, OViz is the one developed by Akbas et al. [62] which represents much of the information related to physical building elements and building occupants' interaction factors. Akbas et al. [62] state the OViz creates "….spatio-temporal representations of user behavior, building component states, and energy consumption". Human Thermal Model (HTM) was also developed by Holopainen [63] which analyzes thermal interactions between the human body and the indoor environment by means of a finite difference heat balance method. The behavior part of these models is usually based on empirical data Hoes et al. [31]. However, a comprehensive list of user activities was ignored in these models [39].

4. User satisfaction adaptive behavior to assess energy efficient buildings

According to mentioned issues and problems, it has been proven that user satisfaction was not considered as an interconnected criterion in correlation with energy efficiency in sustainable building assessment tools. Among diverse aspects of building user satisfaction, 'user satisfaction from adaptive behavior' was not yet studied in sustainable building assessment tool development, which may dependently affect energy consumption. Hence, this research emerges with the idea to identify and establish user satisfaction adaptive behavior in energy efficient indoor environment design of sustainable office buildings. Relatively, the research is to address the research question; "*what are the user satisfaction adaptive behavior applied to assess energy efficient buildings' indoor environment?*"

This research scoped in 'design' phase of 'office' building life cycle. The scope on 'design' phase is significant in comparison with the traditional approach to evaluate user satisfaction in operational phase of the project life cycle.

Furthermore, the research focused on building indoor cooling and lighting qualities. According to previous study conducted by Keyvanfar et al. [64], the building users' dissatisfaction from adaptive behaviors contributed to increase in building energy consumption. Among other energy consumption sectors, included, Building facilities (e.g. elevator), and Working equipment (e.g. printers, and computers), building users' satisfaction from adaptive behaviors affect cooling and lighting systems' energy consumption [64]. Keyvanfar et al. [64] concluded from their research that building users are not satisfied with the tenant energy efficient features and they may adapt building designs and building cooling and lighting technical systems according to their own satisfaction levels, which causes higher energy consumption. Moreover, Holopainen et al. [54] stated that building indoor flexible design can avoid excessive heating and cooling, while it may also provide a non-acceptable degree of user satisfaction. With respect to prior research, the current research focused on building indoor cooling and lighting qualities.

5. Research methodology

The methodology of this research is in two phases. First phase was to conduct a systematic literature review to identify user satisfaction adaptive behaviors in energy efficient office buildings. Secondly, the research was to validate the literature review findings on user satisfaction adaptive behaviors through an expert input study. The following sections present the phases, in details.

5.1. Systematic literature review

In first phase, the research organized the literature review study in a systematic process to investigate user satisfaction adaptive behaviors in the existing literatures. In comparison with traditional narrative reviews, this systematic process has prominent by adopting a replicable, scientific, transparent and detailed process. The systematic process is somewhat similar to Systematic Review Analysis method introduced by Cook et al. [65], Cook et al. [66], and Wolf et al. [67]. Undertaking systematic review process is regarded as a 'fundamental scientific activity'. The systematic process aimed at minimizing bias through exhaustive literature searches of published and unpublished studies and by providing an audit trail of the review's procedure and conclusion.

To conduct the process, a set of keywords (i.e. searching codes) have been surfed via internet searching. The keywords undertaken were building user adaptive behavior in energy efficient buildings, user adaptive behavior in energy efficient environment, user life style in energy efficient buildings. The search was conducted on available online databases from which a set of published papers, books, reports, and standards were identified. 'Google Scholar Citation Report' was surfed for the cited articles of the same materials if its title matched with searching keywords. Content analysis was conducted on each literature document to investigate the user satisfaction adaptive behavior. Fig. 1 illustrates the process flow conducted in the systematic review process.

6. Definition of user satisfaction from adaptive behavior in energy efficient building design

The research conducted systematic review process to identify the definition of User Adaptive Behavior in Energy Efficient Building studies (see Fig.1, online searching keywords). There is a limited literature available on definition of user adaptive behavior. Brager and de Dear [68] defined user adaptation as all activities to 'fit' the indoor climate to self or collective requirements. Liu et al. [69] stated that adaptive behavior can be conscious or unconscious while multiple environmental factors can have effects on it (e.g. climate, culture and economics). Thus, this makes 'adaptive opportunities' approach [70] and 'adaptive constraints' approach [71].

Literature review on adaptive behavior shows that, one of the most useful definitions was stated by Tabak and de Vries [25]. They identified staff (i.e. user) behavior activities as skeleton activities and intermediate activities. They defined skeleton activities as activities that fulfill requirement of staff's job description (e.g. chairing meetings, giving lessons, etc.) and intermediate activities that fulfill the psychological and physical requirement of staff (e.g. getting a drink). Intermediate activities can be non-schedule but skeleton can be scheduled activities. Adaptive behavior is not directly defined, but it can be understood that it is under intermediate behavior umbrella.

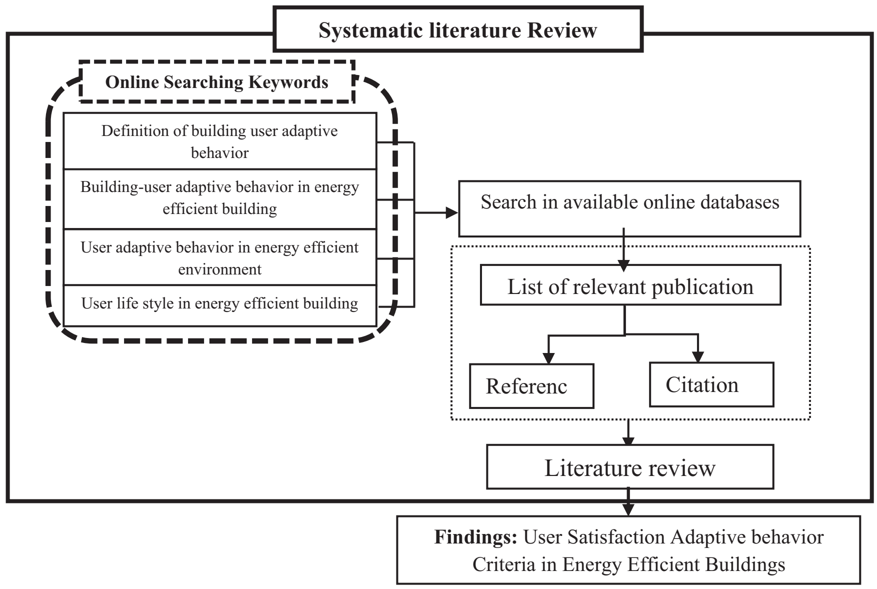

Fig. 1. Process flow of systematic review on literatures in user satisfaction adaptive behavior.

O'Brien and Burak Gunay [34] stated that plentiful statistical significant results from field studies and laboratory investigation show that many criteria impacting building users adaptive behavior and adaptive activities. These criteria include the availability of adaptive measures, building indoor environment design, Mechanical and Electrical Systems, social factors, and views [34]. User thermal adaptation is one of established research domains in this regards. The principle underlying the thermal adaptation reveals that "if a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort" [72]. From the Fanger and Toftum's [73] heat balance view, once body heat transfer is unbalanced, uncomfortable sensation can be reported. In this regard, the undertaken behavior to recover thermal comfort is thermal adaptation [58,74,75].

Based on literature, three modes of adaptation can be derived [76–80]: (1) Behavioral adaptation (e.g. personal, environmental, technological, or cultural), (2) Physiological adaptation (e.g. genetic adaptation or acclimatization), and (3) Psychological adaptation (e.g. habituation or expectation). Brager and de Dear [68] stated that adaptive behaviors may derive 'Technological adaptation' where the building user attempt to adjust the indoor environmental conditioners (e.g. fan), 'Psychological adaptation' where user's indoor expectation and perceived control is enhanced, 'Personal adaptation' where user's self-adjustment happens (e.g. cloth adjustment), and 'Physiological adaptation' where the human body is regulating the heat balance automatically.

In conclusion, considering previewed definitions on adaptive behavior in an Energy Efficient Building, this study defines adaptive behavior as follows:

Behavior which express user's personal or environmental adjustment in response to following indoor conditions:

– Off time running of energy consumable systems.
– Slightly uncomfortable indoor environmental condition which is not considered by them as an unacceptable indoor condition.

The definition of this study on adaptive behavior covers only the technological and personal aspects. Psychological, and Physiological adaptation was not covered. Psychological adaptation is dynamic and cannot be foreseen accurately in design phase of project life cycle. It is obvious (from law of causality) that 'Physiological' adaptation is prime (cause) to 'Technological' and 'Personal' adaptation (effect). Thus, measuring dissatisfaction 'Technological' and 'Personal' adaptation study is eliminating dissatisfaction from 'Physiological' adaptation.

7. Control variables on user satisfaction from adaptive behavior research

In the extraction process of user satisfaction adaptive behaviors from reviewed literature, two control variables have been undertaken, namely Users' Cultural and Social Dimensions and Users' Attitude and Beliefs. The research considered these variables as the control variables to investigate most relevant user satisfaction adaptive behaviors affecting energy consumption of building.

- **Users' cultural and social dimensions**: According to literature, one of the control variables in research on satisfaction from environmental condition in response to cooling system is the cultural and social contextual dimension of users [58,72,80–83]. While, there is no strong evidence that this 'cultural and social dimension' has been significantly covered by researchers. Researchers by the 'cultural and social dimension' referred to the dressing code and clothing habit/behavior of occupants of a particular building, workplace culture, having a siesta in the heat of the day, local and vernacular architecture, traditional means of construction and demographics. However, none of these factors have been investigated as a special subject.
- **Users' attitude and beliefs:** Another control variable in research on satisfaction from environmental condition in response to cooling system is building users' attitude and beliefs. de Dear [79] argued that occupants' attitudes and beliefs towards environment may boost the 'forgiveness' factor in the assessment of conditions provided by building systems. However, according to Jensen et al. [84], people generally tend to distance themselves from behavior that might be considered too different and troublesome. In addition, as Edwards [85] pointed out environmental attitudes are not always translated into action and may impact negatively on people's productivity. Lan et al. [86] reported that the loss of productivity has already been detected at a slightly unsatisfactory level of cooling condition.

8. Building user satisfaction adaptive behavior in energy efficient indoor environment

The study focused on identifying and establishing adaptive behaviors which are in response to indoor conditions provided by Cooling and Lighting systems in an energy efficient office building. The following sub-sections present the identified adaptive behaviors and association between user satisfactions in compliance with the adaptive behavior.

8.1. Adaptive behaviors in response to indoor environmental conditions provided by cooling systems

This section describes the list of adaptive behaviors extracted from literature. Different scopes of energy efficient indoor conditions provided by cooling system are understood including; Slightly Warm Environment, High Ventilation, Low Ventilation, High Velocity, and Low Velocity. Corresponding to the mentioned selected energy efficient indoor conditions, a list of sixteen adaptive behaviors have been identified.

Fisher [87] defined personal control by stating "individuals with control can act to change or reverse situations which are disliked." Researchers have mainly investigated positive effect of personal control on satisfaction from overall work environment [38,88–93]. Research of Leaman and Bordass [94] shows that users perceived work performance was higher in buildings where users have had more control over their environments, such as temperature and ventilation.

One of the early citations to introduce adaptive behavior is Macfarlane [95]. He addressed behavioral adjustment; such as wearing light clothing and restraining physical action. There are studies that focus on clothing adjustments by Nicol [58] and Humphreys and Nicol [72]. Their studies observed that adjustment of activity level is one of main building users adaptive behaviors [96]. This is further supported in several studies [79,97,98]. Benton and Brager [99] conducted a study on effectiveness of 'take a break', or, 'cold drink' in thermal comfort.

Baker and Standeven [70] indicated adjustments to clothing or to furniture, doors, windows, shades, fans or any other part where user is applying adaptation to the environment. Furthermore Nicole [54] addressed 'opening windows', 'closing blinds' or 'switching on a fan'.

The feedback system exists since the early 80's. The aim of this system is to minimize effect of user's adaptation to the environment in building. The common characteristics of feedback systems are, user friendliness; actual consumption; frequent feedback; interaction and choice; appliance-specific; comparative; and given over an extended time period [100,101]. Geller et al. [102] is one of the first citations in this discipline. In a review of thirty-eight feedback studies carried out by Darby [103] energy savings of 10–15% is reported. Daily written feedback on energy consumption was used to promote conservation of building energy and to ascertain some limits on temperature [104,105]. Froehlich [95] states there are ten diverse design dimensions of feedback technology as the potential of feedback to change energy consumption behavior in buildings. de Dear and Brager [80] stated that feedback models of thermal comfort have the following characteristics: (1) convert subjects (i.e. individuals) from passive recipients of indoor thermal environment to active participants who create their own expected environment by interacting with the thermal environment and by establishing a closed-loop feedback system; (2) require large amounts of data that are obtained from field tests and questionnaires in real buildings; and (3) draw on research subjects who work or live in buildings and respond reliably to indoor thermal environmental conditions. There are market based feedback systems currently operating. The problems in these systems are the data is not comprehensive [106,107].

The requirement study of feedback systems is one of the research domains [108]. Recently, there is an effort by Haldi and Rabinson [30]. They develop a feedback system which final adjustment to the environment shall depend on several indoor and outdoor data captured by sensors. The user may instruct the feedback system to adjust the environment (e.g. opening of window) while the final opening or closing happen based on automated decision making in the feedback system. In this process users' adaptive behavior is to order specific adjustment in the environment which previously is conducted manually. Indeed, the efficient adjustment to the environment is aimed by this type of system.

Understanding the two control variables and reviewed literature this section presents adaptive behaviors in response to environmental conditions provided by cooling system. Table 1 outlines sixteen users' adaptive behavior. The user's adaptive behaviors have been mainly clustered into two categories, 'self-adaptation' and 'adaptation to the environment' (i.e. working environment),

- **Self-adaptation:** The 'self-adaptation' category involves five behaviors which were proposed in response of building users' to control slightly warm enevironmnet. Self-adaptation behaviors are a set of personal activities individuals do to balance self-body thermal condition against the outdoor environmental conditions.
  - **Drinking cold beverages:** Benton and Brager [99] and Brager and de Dear [68] considered this as adaptive behavior of building users. Drinking cold beverages considered in response to slightly warm indoor environment. It is in reference to cooling adaptation purpose. Indeed based on definition of adaptive behavior study considered 'drinking cold beverages' to some extent within which it is not considered by user as an unaccepted behavior.
  - **Less-sweating life style:** This adaptive behavior is stated by Brager and de Dear [68]. This life style considered in response to slightly warm indoor environment in reference to user's practice in following life style as code for cooling adaptation purpose (e.g. cutting hair, changing diet).
  - **Restraining physical activity level:** This adaptive behavior has been cited since late 1970's by Macfarlane [95]. Brager and de Dear [68] and Rowe [109] further indicated 'Restraining physical activity level' as adaptive behavior. This behavior was considered in response to slightly warm indoor environment. It is in reference to user's reduction in activity level cooling adaptation purpose. Based on definition of adaptive behavior this study considered these behaviors to some extent within which it is not considered by user as an unaccepted behavior.
  - **Changing or adjusting cloths from warm to cool:** There are a number of authors who have indicated adjustment of clothes as adaptive behavior [29,68–70,72,99]. This users' behavior is in response to slightly warm indoor environment. It is in reference to user's self- adaptation by changing or adjusting cloths.
  - **Decreasing level of body skin moisture:** Schweiker and Shukuya [110] indicated this behavior in their study. This users' behavior is in response to slightly warm indoor environment. It is in reference to user's self-adaptation by drying the body moisture for cooling adaptation purposes (e.g. using tissue to dry the face).
- **Adaptation to the environment:** 'Adaptation to the environment' is a set of activities with which individuals balance

Table 1
Summery of review on users' adaptive behaviors in response to indoor conditions provided by energy efficient cooling system.

Users' adaptive behaviors in response to energy efficient cooling system		Description	Indoor conditions	Citation
Self-adaptation	Drinking cold beverages	It is reference to user drinking as an unaccepted behavior.	Slightly warm	[99,111]
	Less-sweating life style	It is in reference to user's life style codes, e.g. cutting hair, changing diet.		[111]
	Restraining physical activity level	It is in reference to user's reduction in activity level cooling adaptation purpose.		[68,95,109]
	Changing or adjusting cloths from warm to cool	It is in reference to user's changing or adjusting cloths.		[29,68,69,72,99]
	Decreasing level of body skin moisture	It is in reference to user's drying body moisture, e.g. using tissue to dry the face.		[110]
Adaption to the environment	Taking a break and moving to cooler location	It is in reference user take a temporary break to move to cooler location, e.g. going to a cooler room or balcony.	• Slightly warm • Low ventilation • Low velocity	[111]
	Changing position and direction	It is in reference to user's temporary or permanent adjustment of seating position, e.g. changing orientation of desk.		[70,111]
	Adjusting furniture material	It is in reference to user's temporary or permanent adjustment of buildings furniture materials, e.g. changing warm material to cold material.	Slightly warm	[68,70,111]
	Adjusting finishing material	It is in reference to user's temporary or permanent adjustment of buildings finishing materials, e.g. changing warm color to cold color.		[68,70,111]
	Opening or closing door(s) using feedback system	Opening or closing door depends on several indoor and outdoor data by using an automated decision making of the feedback system.	• Slightly warm • Low ventilation • Low velocity	[30]
	Opening or closing operable window (s)	It is in reference to user may open/close the window(s) based on his/her self-preference.		[30,39,61,68,85,89–92,94,75,114–116]
	Opening or closing window(s) using feedback system	This depends on several indoor and outdoor data. The user may instruct the feedback system by using an automated decision making of the feedback system.		[30]
	Using the portable fan	It is while the fan is not provided as building facility and it is an energy consumable device, e.g. using a self-USB fan.		[30,70,72,91,117]
	Using hand fan	It shall be considered that in the case that fan is not provided as building facility which is not an energy consumable device.		[30]
	Adjusting room's thermostat	It is in reference to user's direct adjustment in room's thermostat, e.g. reducing the thermostat sensitive temperature.		[85,89–92,116,117]
	Adjusting air-condition operative hours	It is in reference to users' direct adjustment in running time of cooling systems, e.g. turning the cooling system off based on occupancy rate.	Off time running	[74,85,89–92,100,111,115]

indoor condition of environment through adjusting accessible and available cooling facilities and equipment. Considering the findings of literature and the scope of current study the adaptive behavior in this class constituted to eleven behaviors.

- **Taking a break and moving to cooler location:** This adaptive behavior is indicated by Brager and de Dear [68] in response to indoor conditions like; slightly warm, low ventilation and low velocity provided. It is in reference activity where users' take a temporary break to move to cooler location for cooling adaptation purposes (e.g. going to a cooler room or balcony).
- **Changing seating position and direction:** Baker and Standeven [70] as well as Brager and de Dear [68] stated changing seating position and direction as type of adaptive behavior. This behavior is in response to indoor conditions like slightly warm, low ventilation and low velocity provided. It is in reference to user's temporary or permanent adjustment of seating position for cooling adaptation purposes (e.g. changing orientation of desk).
- **Adjusting furniture material:** Identified from literature study by Baker and Standeven [70], Brager and de Dear [68], and Brager and Baker [111] introduced this adaptive behavior. This users' behavior is in response to slightly warm indoor environment. It is in reference to user's temporary or permanent adjustment of buildings furniture materials for cooling adaptation purposes (e.g. changing warm material to cold material).
- **Adjusting finishing material**: This adaptive behavior stated by Brager and de Dear [68], Baker and Standeven [70], Brager and Baker [111]. This user's behavior is in response to slightly warm indoor environment. It is in reference to user's temporary or permanent adjustment of buildings finishing materials for cooling adaptation purposes (e.g. changing warm color to cold color).
- **Opening or closing door(s) using feedback system**: Haldi and Rabinson [30] introduced this behavior in their research. This behavior is in response to indoor conditions like; slightly warm, low ventilation and low velocity provided. It is in reference to user's door-opening-closing for cooling adaptation purposes. Opening or closing were depends on several indoor and outdoor data. The final opening or closing happened based on automated decision making in the feedback system.
- **Opening or closing operable window(s):** This adaptive behavior was studied by several authors [30,38,39,61,68,85,89–93,112–114]. This behavior covers indoor conditions like; slightly warm, low ventilation and low velocity provided. It is in reference to cooling adaptation purposes where building user may open the window based on self-preference.
- **Opening or closing window(s) using feedback system:** Haldi and Robinson [30] considered this behavior in their research. This behavior covers indoor conditions like; slightly warm, low ventilation and low velocity provided. It is in reference to user's widow-opening-closing for cooling adaptation purposes. This depends on several indoor and outdoor data. The user may instruct the feedback system. The final opening happen based on automated decision making in the feedback system.
- **Using the portable fan:** This behavior stated by Huizenga et al. [115], Haldi and Robinson [30], Oseland (1994); Baker and Standeven [70]; Newsham et al. [115], Humphreys and Nicol [72]. This behavior shall be considered in indoor conditions like; slightly warm, low ventilation and low velocity provided. It is in reference to user's use of portable fan for cooling adaptation purposes. It is while the fan is not provided as building facility and it is an energy consumable device (e.g. using a self-USB fan).
- **Using handy fan:** This behavior addressed by Haldi and Robinson [30] in response to indoor conditions like; slightly warm, low ventilation and low velocity provided. It is in reference to user's use of hand fan for cooling purposes. It shall be considered that in this case the fan is not provided as building facility and it is not an energy consumable device.
- **Adjusting room's thermostat:** This adaptive behavior discussed by Peffer et al. [116], Lee and Brand [89], Abbaszadeh et al. [90], Edwards [85], Zagreus et al. [91], MacMillan [92], Newsham [93]. This adaptive behavior is in response to indoor conditions like; slightly warm, low ventilation and low velocity provided. This activity is in reference to user's direct adjustment in room's thermostat (e.g. reducing the thermostat sensitive temperature).
- **Adjusting air-condition operative hour**: This adaptive behavior considered in this study is based on research done by Zagreus et al. [92], Lee and Brand [89], Abbaszadeh et al. [90], Edwards [85], MacMillan [92], Newsham [93], Brager and Baker [111], Brager et al. [74], and Liu et al. [69]. This activity is considered as an adaptive behavior in response to off time running of cooling systems. This activity is in reference to users' direct adjustment in running time of cooling systems (e.g. turning the cooling system off based on occupancy rate).

The current study applied all the mentioned users' adaptive behavior in response to indoor condition provided by energy efficient cooling system. This is presented in Table 1.

8.2. Adaptive behaviors in response to indoor environmental conditions provided by lighting systems

Interior lighting quality must meets human needs for an individual's well-being such as visibility, activity, communication, mood, comfort, health and safety, and esthetic judgment [117]. One of the first citations on adaptive behavior in indoor lighting condition was Trengenza and Waters [118] where, they developed simulation models. Lighting is a controversial issue in sustainable building design regarding enhancing user satisfaction and performance, especially, in the office buildings [85,91–93]. There are a numbers of building assessment frameworks which considered quality lighting; they included, the Leadership in Energy and Environmental Design (LEED), Green Star, the Hong Kong Building Environmental Assessment Method (HK-BEAM), the Comprehensive Assessment System for Built Environment Efficiency (CASBEE), and the Sustainable Building Tool (SBTool).

There are efforts by Veitch and Newsham [119] on lighting quality as user's perception on suitability of indoor condition to fulfill occupancy needs. They defined the needs as; visual performance; post-visual performance (e.g., reading, eating, seeing, walking); social interaction and communication; mood state (i.e. happiness, alertness, satisfaction, and preference); health and safety; and esthetic judgments (i.e. assessments of the appearance of the space or the lighting).

Luminance level can be described as the "…total amount of light falling on a given surface" [120] which measured as horizontally at level which occupants typically works [121]. Previous studies highlighted a number of parameters, including, low luminance level, high luminance level, glare, spectrum of light, reflex, which are in compliance with user satisfaction assessment. Poor lighting conditions can produce discomfort problems [122]. Glare from distant light fixtures that are blocked by high partitions, and inadequate light level on task surfaces can make visual discomfort that results in

Table 2
Summery of review on user's adaptive behaviors in response to indoor conditions provided by energy efficient lighting system

Building user's adaptive behaviors in response to energy efficient lighting system		Description	Indoor conditions	Citation
Electric lighting	Covering room surface(s)	It is in reference to user's direct adjustment in room's surfaces to minimize indoor conditions, e.g. using wallpaper.	• Reflection of electrical lighting from window, wall, or ceiling • High or low luminance level • Glare • Electric light shading	[29,90,121]
	Opening or closing operable curtain(s)	This is in reference to user's direct adjustment on curtain(s) using hand or remote to minimize indoor conditions.		[29,90,93,121,128]
	Adjusting electric lighting operative hour	It is in reference to users direct adjustment in running time of lighting devices, e.g. turning the lights off based on occupancy rate.	Off-time running	[68,70]
	Using desktop USB lamp instead of electrical lighting	It is in reference to users make direct adjustment in running time of lighting devices (e.g. turning the lights off based on occupancy rate).		[93,117,119]
	Adjusting desktop or task surface	It is in reference to user's direct adjustment in task surfaces to minimize the indoor condition, e.g. using screen protector.	• Reflection of electrical lighting from screen, window, wall, or ceiling • High or low luminance level • Glare • Electric light shading • High or low spectrum level	[121,143,144]
	Switching lighting(s) manually	It is in reference to user's manually switching lights to minimize the indoor condition.		[90,123,128,144]
	Switching lighting(s) by feedback system	This depends on several data measureable by sensors and data feeds into the system by other user(s). The final switching happen based on automated decision making of the feedback system.		[30]
Daylighting	Changing position or direction of furniture	It is in reference to user's position adjustment to minimize the indoor condition, e.g. changing chair position.	• Reflection of natural lighting from screen , window, wall, or ceiling • High or low luminance level • Glare • Shading and/or sunlight penetration	[68,70]
	Covering wall, window, or ceiling surface	It is in reference to user's direct adjustment in room's surfaces to minimize the indoor condition, e.g. using wallpaper or painting.		[29,90,121]
	Opening or closing operable curtain(s)	It is in reference to user's opening and closing of curtain to minimize the indoor condition.		[29,90,128,145]
	Adjusting curtain(s) by remote control	It in response to all type of indoor condition subjects to open and close the curtain by remote control.		[90,146]
	Adjusting curtain(s) by feedback system	This depends on several data measureable by sensors and data feeds into a system by other users. The final switching happen based on automated decision making of the feedback system.		[90,146]
	Opening or closing operable window(s)	It is in reference to user's manual opening or closing window to minimize the indoor conditions.		[29,30,39,61,68,88,–93,112–114]
	Opening or closing window (s) by feedback system	The final switching depends on several data measured by sensors and data feeds into the system by other users, and will act based on automated decision making of the feedback system.		[100–105,123,128]

dissatisfaction, reduce accuracy in task performance and increase the time of doing tasks [93]. In contrast, high quality lighting conditions can reduce distractions and discomfort by providing building users with appropriate working conditions and esthetic elements for psychological comfort. Level of lighting luminance, amount of glare, and the spectrum of light can also affect work performance because lighting directs attention or influences arousal or motivation [123].

There are two main categories of scopes in lighting condition studies applied in previous energy efficient building research, including, Electrical (Artificial) Lighting and Day-lighting (i.e. Natural Lighting). Daylighting has often been considered a useful source of energy savings and a means to increase users' visual comfort in sustainable buildings [124]. Daylighting can reduce electric lighting energy consumption, and 20–60 percent of overall building energy use can be saved through the integration of daylighting strategies [125]. Hence, there is a crucial need in office building indoor design to incorporate daylighting strategies as methods for energy saving by reducing electric lighting levels [126]. Furthermore, daylighting can increase employees' satisfaction, which leads to improved work performance by providing more comfortable working environments [119]. Studies on comparing effect of daylight and electrical light on users shows daylight would result in less discomfort than electric light [91,119,127,128]. According to literature review, the daylight from windows enhances work performance, comfort, and satisfaction [129,130]. However daylight may result in glare and unbalance luminance level [131–137]. Staff satisfaction and visual comfort leading to improved worker performance can be increased by incorporating day lighting controls and other electric lighting controls [94,125]. Indeed, users in sustainable buildings have often shown low satisfaction with control over lighting conditions such as control over light switches compared to those in conventional buildings [90].

Veitch and Gifford [128] indicated that increased control led to a performance decrement among the users. Lindelöf and Morel [138] evaluated occupants' visual discomfort as by frequency of adaptive behavior to the environment, using blinds and lighting controls as an example. Sutter et al. [139] and Inkarojrit [140] did research and supported this concept. Recently Zhang and Barrett [141] stated that glare protection is the main factor in lowering the blinds which is supported by number of researchers [30].

Veitch and Newsham [119] conducted a research to evaluate lighting effects on user's work performance in office buildings. The results of the research identified that energy-efficient lighting and satisfactory lighting can be compatible. Furthermore, findings of Center for the Built Environment (CBE) at the University of California, Berkeley researched on user satisfaction in 21 sustainable buildings and non-sustainable buildings indicated that users had complaints about 'not enough daylight,' 'reflections in computer screens,' and 'too dark' in lighting conditions of both sustainable and non-sustainable buildings, and that there was no difference in the frequency of lighting condition complaint between both building types [90]. Cost-effective Open-Plan Environments (COPE) project conducted by the National Research Council Canada-NRCC [93] showed that user satisfaction is affected by total luminance level and glare, while the overall environmental satisfaction was greatest for users with access to daylight.

This section presents results of literature review on user's adaptive behaviors in response to lighting condition in energy efficient building. Table 2 outlines the fourteen identified behaviors. The user adaptive behaviors have been clustered into two main categories, 'Electric Lighting' and 'Daylighting (i.e. Natural Lighting)'.

- **Electric Lighting:** The 'Electric Lighting' category involves seven behaviors that were identified in previous studies to control the problems including; reflection of electrical lighting from screen, window, wall, or ceiling, high or low luminance level, shading of electrical lighting, high or low spectrum level, and glare. Besides, there are behaviors in response to 'off time running of lighting devices'. These features are
  - **Covering room surface:** This adaptive behavior is stated by Estes et al. [12], Abbaszadeh et al. [142], Goto et al. [29]. This adaptive behavior is in response to indoor conditions like; reflection of electrical lighting, high or low luminance level, glare, and electric light shading. This activity is in reference to user's direct adjustment in room's surfaces to minimize the mentioned indoor condition (e.g. using wallpaper).
  - **Opening or closing operable curtain(s):** Veitch and Gifford [128], Estes et al. [12], Newsham [93], Abbaszadeh et al. [142], Goto et al. [29] indicated this adaptive behavior in their research. This adaptive behavior observed in response to indoor conditions like; reflection of electrical lighting, high or low luminance level, glare, and electric light shading. This is in reference to user's direct adjustment on curtain(s) using hand or remote control to minimize the mentioned indoor condition.
  - **Adjusting electric lighting operative hours:** There are a number of research works that indirectly mentioned this adaptive behavior, however Baker and Standeven [70] and Brager and de Dear [111] have directly highlighted it. This activity is considered as an adaptive behavior in response to off time running of electrical lighting systems. This activity is in reference to users direct adjustment in running time of lighting devices (e.g. turning the lights off based on occupancy rate)
  - **Using desktop USB lamp instead of electrical lighting:** This adaptive behavior was indicated in a research report by NRCC [93]. This activity is in response to off time running of electrical lighting systems within which users make direct adjustment in running time of lighting devices (e.g. turning the lights off based on occupancy rate).
  - **Adjusting desktop or task surface:** This behavior is indicated in literature in response to indoor conditions like reflection of electrical lighting, high or low luminance level, glare, electric light shading, and high or low spectrum level [93,112,143,144]. This activity is in reference to user's direct adjustment in task surfaces to minimize the mentioned indoor condition (e.g. using screen protector).
  - **Switching lighting(s) manually**: This adaptive behavior is indicated by National Electrical Manufacturing Association-NEMA [123], Abbaszadeh et al. [142], Veitch and Gifford [128], Newsham [93]. This is considered in response to indoor conditions like reflection of electrical lighting, high or low luminance level, glare, electric light shading, and high or low spectrum level. This activity is in reference to user's manually switching lights to minimize the mentioned indoor condition.
  - **Switching lighting(s) using feedback system**: This adaptive behavior is considered by Haldi and Robinson [30] in response to indoor conditions like; reflection of electrical lighting, high or low luminance level, glare, electric light shading, and high or low spectrum level. This activity is in reference to user's behavior in lighting adaptation purposes. This depends on several data measureable by sensors and data feeds in to system by other user. The final switching happen based on automated decision making in the feedback system.
- **Daylighting:** The category of 'Daylighting' includes user's seven adaptive behaviors which have been identified as different in controlling and adjusting day lightening in workplaces. There are feature in response to indoor environmental condition like reflection of natural lighting from screen, window, wall, or

ceiling, high or low luminance level, glare, and shading and/or sunlight penetration.

- **Changing position or direction of furniture:** This adaptive behavior is considered by Brager and de Dear [111] and Baker and Standeven [70]. This may happen in response to all type of indoor conditions subject to user's adaptive behavior, including reflection of natural lighting from screen, window, wall, or ceiling, high or low luminance level, glare, and shading and/or sunlight penetration. This activity is in reference to user's position adjustment to minimize the mentioned indoor condition (e.g. changing chair position).
- **Covering room surface:** This adaptive behavior is stated by Estes et al. [121], Abbaszabeh et al. [142], and Goto et al. [29]. This adaptive behavior is in response to indoor conditions like reflection of natural lighting, high or low luminance level, glare, and shading and/or sunlight penetration. This activity is in reference to user's direct adjustment in room's surfaces to minimize the mentioned indoor condition (e.g. using wallpaper or painting)
- **Opening or closing operable curtain(s):** This behavior is presented by several authors [29,128,142,145]. This is in response to all types of indoor conditions subject to user's adaptive behavior. This activity is in reference to user's opening and closing of curtain to minimize the indoor condition. The indoor condition covers reflection of natural lighting, high or low luminance level, glare, and shading and/or sunlight penetration.
- **Opening or closing curtain(s) by remote control:** Singhvi, et al. [146], and Abbaszadeh et al. [142] stated this adaptive behavior in their study. This is in response to all type of indoor condition subject to opening and closing of a curtain by remote control to minimize the mentioned indoor condition. it shall be considered in response to reflection of natural lighting, high or low luminance level, glare, and shading and/or sunlight penetration.
- **Opening or closing curtain(s) by feedback system:** This adaptive behavior is considered by Abbaszadeh et al. [142], and Singhvi, et al. [146] in response to indoor conditions like reflection of natural lighting, high or low luminance level, glare, and shading and/or sunlight penetration. This activity is in reference to user's inquiry in a feedback system to minimize the mentioned indoor condition. It is in reference to user's behavior in natural lighting adaptation purposes. This depends on several data measureable by sensors and data feeds into a system by other users. The final switching happen based on automated decision making in the feedback system.
- **Opening or closing operable window(s):** This adaptive behavior is a multipurpose user's adaptive behavior. In this case it is in response to indoor conditions like; Reflection of natural lighting, High or low luminance level, Glare, and Shading and/or sunlight penetration. Several authors have mentioned on the existence of this adaptive behavior [30,39,61,68,89,85,91–93,112–114,142]. This activity is in reference to user's manual opening or closing window to minimize the mentioned indoor conditions.
- **Opening or closing window(s) by feedback system**: Thisadaptive behavior is considered by researchers in response to indoor conditions like reflection of natural lighting, high or low luminance level, glare, and shading and/or sunlight penetration [123,128,142]. This activity is in reference to user's inquiry in a computerized feedback system to minimize the mentioned indoor condition. It is in reference to user's behavior in natural lighting adaptation purposes. The final switching happen based on automated decision making in the feedback system and depends on several data measureable by sensors and data feeds into the system by other users.

9. Validation of user satisfaction adaptive behavior

In second phase, the research conducted 'Expert Input Study' to validate the literature review findings on building user satisfaction adaptive behaviors in energy efficient indoor environment.

Field expert Delphi structured Close Group Discussion was used as the method of data collection. According to Ozer [147] 'Group Decision Making Methods' are useful in judgmental tasks, produce better decisions than individuals, reduce effects of individual bias, and also, the solutions are more likely to be accepted. Delphi structured CGD was used as the method of data collection in the futuristic analysis. Delphi method is the most applicable group decision making method [148,149]. Delphi is able to cover 'non-alternative selection' decision making which can instruct the CGD.

A structured fixed format self-reporting questionnaire form was designed to be filled up in the interviews. The interviews will validate findings of the literature review, based on expert's judgment in the scale of 1 for Weak to 5 for Excellent. The interview questionnaire form collected experts' inputs on validation of 'the proposed user satisfaction adaptive behaviors'. Experts were asked by researcher to propose more relevant user satisfaction adaptive behavior based on their experiences, if any. At the end of each interview, the researcher asked experts if there was a necessity to conduct interviews with specific other experts(s) as 'resource(s) or expert(s) relevant to the issue'. Researcher asked 'Would you pass the absolute decision to the proposed expert?' or shall researcher take 'Minimum vote between respondent and proposed expert', if expert(s) introduced 'resource(s) relevant to the issue'.

Based on implemented purposive sampling method, a total of eight participants were involved, two field-experts who had an experience in building energy management, five field-experts who had experience in building facility management, and one who had experiences in assessment model development. In order to record judgments of experts, the research conducted four group decision making sessions. Each session took approximately one hour.

Data analysis was conducted using Grounded Group Decision Making (GGDM) method. Lamit et al. [150] state the GGDM method is suitable if decision makers in a close group discussion ask for another close group discussion session by other 'resource (s) relavent to that issue'. The GGDM provides numbers of conditions and sub-conditions that should be considered in any case of group decision making, if there is a need for several close group discussions [150].

Adapted from Lamit et al. [150] GGDM formula is as shown in Eq. (1). $FW(a_i)$ is to calculalte final weight (FW) of sub-issue number 'i', (a_i), of the discussion.

$$FW(a_i) = \left(\sum_{j=1}^{n} (\min\{WP_j,\ WPr_j\} \times SV_j)\right) \times a_i, \quad \text{for } i = 1, 2, 3, \ldots, m \tag{1}$$

where

WP_j , refers to assigned weight by participants number 'j' in close group discussion for sub-issue 'a_i',
WPr_j , refers to assigned weight by resource(s) relevant to the issue, whom introduced by participants number 'j' in close group discussion for sub-issue 'a_i',
a_i, refers to sub-issue of discussion,
$FW(a_i)_{max}$, referred to maximum possible weight can be given for sub-issue 'a_i',

Table 3
Summary of GGDM data analysis on validation of users satisfaction adaptive behaviors in response to energy efficient cooling systems.

Approach.	**Building users' adaptive behaviors in response to indoor conditions provided by energy efficient cooling systems**	**Validation session 1**							**Validation session 2**				**Validation session 3**										**Validation session 4**							**Cons. (%)**	**GGDM Consensus**
		Participant 1			Participant 2				Participant 3				Participant 4			Participant 5			Participant 6				Participant 7			Participant 8					
		WP	**WPr**=c-WP3	**c-WP**	**WP**	r-**WP**=c-WP4	**c-WP**	**SV**	**WP**	**WPr**=–	**c-WP**	**SV**	**WP**	**WPr**=c-WP7	**c-WP**	**WP**	**WPr**=WP7	**c-WP**	**WP**	**WPr**=c-WP7	**c-WP**	**SV**	**WP**	**WPr**=–	**c-WP**	**WP**	**WPr**=c-WP5	**c-WP**	**SV**		
Self-adaptation	**C1**-Drinking cold beverages	3	5	3	4	5	4	1	5	–	5	1	5	5	5	5	5	5	–	5	5	3	5	–	5	–	5	5	4	97	Aprv.
	C2-Less-sweating lifestyle	2	5	2	3	4	3	1	5	–	5	1	4	5	4	5	5	5	–	5	5	3	3	–	3	–	5	5	4	88	Aprv.
	C3-Restraining physical activity level	2	5	2	3	4	3	1	5	–	5	1	4	5	4	5	5	5	–	5	5	3	5	–	5	–	5	5	4	92	Aprv.
	C4-Decreasing body skin temperature	3	5	3	4	5	4	1	5	–	5	1	5	5	5	5	5	5	–	5	5	3	5	–	5	–	5	5	4	97	Aprv.
	C5-Changing/adjusting cloths from warm to cool	2	5	2	3	4	3	1	5	–	5	1	4	5	4	5	5	5	–	5	5	3	5	–	5	–	5	5	4	92	Aprv.
	C6-Drying body skin moisture	4	5	4	3	3	3	1	5	–	5	1	3	4	3	4	4	4	–	4	4	3	4	–	4	–	4	4	4	77	Aprv.
Environment Adaptation	**C7**-Taking a break and moving to cooler location	4	4	4	4	4	4	1	4	–	4	1	4	5	4	5	5	5	–	5	5	3	5	–	5	–	5	5	4	94	Aprv.
	C8-Changing position and direction	3	4	3	4	5	4	1	3	–	3	1	5	5	5	5	5	5	–	5	5	3	3	–	3	–	5	5	4	85	Aprv.
	C9-Adjusting furniture material	2	3	2	4	5	4	1	3	–	3	1	5	5	5	5	5	5	–	5	5	3	5	–	5	–	5	5	4	92	Aprv.
	C10-Adjusting finishing material	3	5	3	5	5	5	1	5	–	5	1	5	4	4	4	4	4	–	4	4	3	4	–	4	–	4	4	4	81	Aprv.
	C11-Opening or closing door(s) using feedback system	2	5	2	3	4	3	1	5	–	5	1	4	5	4	5	5	5	–	5	5	3	5	–	5	–	5	5	4	92	Aprv.
	C12-Opening or closing operable window(s)	3	5	3	4	5	4	1	5	–	5	1	5	5	5	5	5	5	–	5	5	3	5	–	5	–	5	5	4	97	Aprv.
	C13-Opening or closing window(s) using remote	3	5	3	4	5	4	1	5	–	5	1	5	5	5	5	5	5	–	5	5	3	5	–	5	–	5	5	4	97	Aprv.
	C14-Opening or closing window(s) using feedback system	4	3	3	4	5	4	1	3	–	3	1	3	5	3	4	5	4	–	5	5	3	5	–	5	–	4	4	4	86	Aprv.
	C15-Using the portable fan	3	4	3	4	4	4	1	4	–	4	1	4	5	4	5	5	5	–	5	5	3	5	–	5	–	5	5	4	93	Aprv.
	C16-Using hand fan	3	5	3	4	5	4	1	5	–	5	1	5	5	5	5	5	5	–	5	5	3	5	–	5	–	5	5	4	97	Aprv.
	C17-Adjusting room's thermostat	2	2	2	3	3	3	1	2	–	2	1	3	2	3	3	2	2	–	2	2	3	2	–	2		3	3	4	45	n-Aprv.
	C18-Adjusting air-condition operative hours	3	5	3	4	5	4	1	5	–	5	1	5	5	5	5	5	5	–	5	5	3	5	–	5	–	5	5	4	97	Aprv.

Note. WP: participant's rate to the validation aspect, c-WP: conclusion of participant's rate to the validation aspect considered as min $\{WP_j,\ WPr_j\}$, WPr: participant introduced resouce rate to the validation aspect, –: Participant did not provide value, SV: CGD session value considered by the GGDM researcher, Aprv.: the validation aspect is approved based on GGDM consensus rate of more than 70% agreement, n-Aprv.: the validation aspect is not approved based on GGDM consensus rate of not more than 70% agreement.

SV_j, refers to CGD sessions value (SV) considered by the decision researcher which the CGD session included participant number 'j',

In the cases participant(s) did not introduce other resource (s) relevant to the issue, min $\{WP_j, \ WPr_j\}$ will be taken as WP_j. Furthermore, in the cases participant(s) did not vote and left the absolute decision for introduced resource(s) relevant to the issue min $\{WP_j, \ WPr_j\}$ will be taken as WPr_j. Formula (2) indicates the consensus calculation in GGDM for sub-issue 'a_i' based on percentage (%), if the final consensus calculated more than 70% the alternative is selected, and the issue is approved.

$$FW(a_i)\ /FW(a_i)_{\max} = \text{Consensus in } \% \tag{2}$$

10. Data analysis procedure

This study conducted the GGDM data analysis for two categories of behaviors, including, Building users satisfaction adaptive behaviors in response to energy efficient cooling system (C1 to C18) (Table 3), and Building users satisfaction adaptive behaviors in response to energy efficient lighting system (L1 to L18) (Table 4).

In the GGDM implementation process, the researcher asked the experts to validate the behaviors extracted from literature review. Within first session, the researcher added up the following with the consensus of panels, C4-Decreasing body skin temperature using fresh- aqua sprays, C13-Opening or closing window(s) using remote, L1-Changing or direction of furniture, L4-Opening or closing curtain(s) using remote, L6-Using desktop USB lamp instead of the electrical lighting, L17-Opening or closing window (s) using remote.

The researcher appointed the specific value (SV) for each session of CGD. For example, the researcher appointed SV 1 for two first sessions and SV 3 for the session 3 and SV 4 for the session 4 of the 'expert inputs on building user satisfaction adaptive behaviors in response to energy efficient cooling system'. In the first session, two (2) participants (i.e. experts) have been invited. According to the questionnaire form each participants were asked to do 5-point scale ranking for each behaviors. According to Table 3, participant 1 appointed WP equals 3 for 'C1' (i.e. Drinking cold beverages) as his rate of validation. Then the participants were asked to introduce any other resource to validate the list of behaviors, if needed. As can be seen in Table 2, participant 1 introduced participant 3 (WPr=c-WP3). Then the research has to conclude the minimum between WP's weighting value and c-WP3's value.

For example, according the WP column of the participant 3 of Table 3, the researcher had to select the minimum between 3 and 5 as the ranking value indicated for 'C1' (i.e. Drinking cold beverages), which is 3. Then, researcher put this value in the column c-WP for the participant 1 records.

In the second, third, and fourth sessions, all the mentioned process has been done. Then Formulas 1 and 2 of the GGDM have been applied for each behavior. If the consensus rate of the criterion is more than 70%, then that behavior will be approved which can be seen in the column 'Cons %' and the column 'GGDM Consensus' by 'Aprv' marking, otherwise, it will not be approved (i.e.n-Aprv).

For example, for 'C1' (i.e. Drinking cold beverages) the following calculations have been done,

$$(3 \times 1) + (4 \times 1) + (5 \times 1) + (5 \times 3) + (5 \times 3) + (5 \times 3) + (5 \times 4) + (5 \times 4) = 97$$

It means the experts validated and approve this behavior with 97% consensus.

In some cases the participants did not introduced any other sources for the CGD, such as Table 3, participant 3 (i.e. WPr = –). Also, in some cases the participant did not appoint any value, and accepts all identified by his/her introduced expert. For example, Table 3 Participant 6 did not ranked (i.e. WP = –) and introduced participant 7 and claimed he accepted all ranked by participant 7.

11. Expert input validation results

Experts in Delphi structured close group discussions validated the findings of literature study on 'user satisfaction adaptive behaviors'. The GGDM data analysis result shows that expert input reached more than 70% saturation within four group decision making sessions. The group discussion with the experts resulted in seventeen behaviors in response to energy efficient cooling system. 'Adjusting room's thermostat (C17)' was not approved in the analysis. The C17 was dropped from the initial list due to getting 45% saturation. In parallel, the GGDM data analysis resulted with approving all eighteen behaviors in energy efficient lighting system (L1 to L18). All energy efficient lighting behaviors got saturation more than 70%.

12. Discussion

Previous studies emphasizes on merging and unifying adaptive behavior models. The common criteria of those models can be unified in one global-wised adaptive behavior model. However, there are some criteria significantly affecting achieving a proper balance between thermal comfort and energy use, such as, climate [88], clothing norms [32], religion [32], occupancy patterns [34,35], and education tend to mediate our perception of the thermal environment. These criteria cannot be merged together, in turn, should be adjusted to the targeted building's type and functionality.

Several thermal comfort evaluation models have developed, such as, Fanger 's PMV method, Adaptive comfort method, Human Thermal Model, HTM, adaptive predicted mean vote (aPMV) method, and Predicted Mean Vote-Predicted Percent Dissatisfied (PMV-PPD) model. However, it is very critical to integrate these models with user satisfaction from adaptive behavior to achieve more proper balance in trade-off between comfort and energy consumption in office buildings. As Holopainen et al. [54] call it moving towards "sustainable thermal environment", means, "having satisfactory indoor conditions, while ensuring low energy use and running costs, and providing a stimulating indoor environment to ensure well-being and productivity".

Most of the thermal comfort models focus on the average thermal comfort [55]. For example, the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) and PMV-PPD model identify the average recording from the environmental factors (air temperature, air velocity, humidity, radiant) and individual factors (metabolic rate, clothing, activity type) in a comfort value scaling for large groups of users. Most of the environmental factors and individual factors have been established in ASHRAE standard, EN standard, and other related standards, to guide in HVAC system capacity design and facility management in buildings. However, these models cannot establish thermal comfort of all individuals in a large group. In practice, diverse individual thermal preferences cause dissatisfaction from indoor environment by overall. For instance, the PMV-PPD indicates that the environment satisfies PMV $\frac{1}{4}$ 0, 5% of users are dissatisfied. When PMV $\frac{1}{4}$ 1 the

Table 4
Summary of GGDM data analysis on validation of user satisfaction adaptive behaviors in response to energy efficient lighting systems.

Approach.	**Building users' adaptive behaviors in response to indoor conditions provided by energy efficient lighting systems**	**Validation session 1**							**Validation session 2**				**Validation session 3**										**Validation session 4**							**Cons. (%)**	**GGDM Consensus**
		Participant 1			Participant 2				Participant 3				Participant 4			Participant 5			Participant 6				Participant 7			Participant 8					
		WP	**WPr** =c-WP3	c-**WP**	**WP**	r-**WP**=c-WP4	c-**WP**	**SV**	**WP**	**WPr**=–	c-**WP**	**SV**	**WP**	**WPr**=c-WP7	c-**WP**	**WP**	**WPr**=WP7	c-**WP**	**WP**	**WPr**=c-WP7	c-**WP**	**SV**	**WP**	**WPr**=–	c-**WP**	**WP**	**WPr**=WP5	c-**WP**	**SV**		
Electric Lighting	**L1**-Changing or direction of furniture	2	5	2	3	4	3	1	5	–	5	1	4	5	4	5	5	5	–	5	5	3	5	–	5	–	5	5	4	92	Aprv.
	L2-Covering wall, window, or ceiling surface	5	3	3	3	5	3	1	3	–	3	1	5	4	4	5	4	4	–	4	4	3	4	–	4	–	5	5	4	81	Aprv.
	L3-Opening or closing operable curtains	3	5	3	4	5	4	1	5	–	5	1	5	5	5	5	5	5	–	5	5	3	5	–	5	–	5	5	4	97	Aprv.
	L4-Opening or closing curtain (s) using remote	4	3	3	3	5	3	1	3	–	3	1	5	5	5	5	5	5	–	5	5	3	5	–	5	–	5	5	4	94	Aprv.
	L5-Adjusting electric lighting operative hours	3	3	3	4	4	4	1	3	–	3	1	4	5	4	4	5	4	–	5	5	3	5	–	5	–	4	4	4	85	Aprv.
	L6-Using desktop USB lamp instead of the electrical lighting	2	5	2	4	4	4	1	5	–	5	1	4	5	4	5	5	5	–	5	5	3	5	–	5	–	5	5	4	93	Aprv.
	L7-Adjusting desktop or task surface	5	4	4	5	4	4	1	4	–	4	1	4	5	4	5	5	5	–	5	5	3	5	–	5	–	5	5	4	99	Aprv.

	L8-Switching lighting (s) manually	5	5	5	5	4	4	1	5	–	5	1	4	4	4	5	4	4	–	4	4	3	4	–	4	–	5	5	4	86	Aprv.
	L9-Switching lighting (s) using remote	5	4	4	5	5	5	1	4	–	4	1	5	5	5	4	5	4	–	5	5	3	5	–	5	–	4	4	4	79	Aprv.
	L10-Switching lighting (s) using feedback system	2	4	2	4	3	3	1	4	–	4	1	3	5	3	5	5	5	–	5	5	3	5	–	5	–	5	5	4	88	Aprv.
Dayighting	**L11**-Changing position or direction of furniture	2	5	2	4	4	4	1	5	–	5	1	4	5	4	5	5	5	–	5	5	3	5	–	5	–	5	5	4	93	Aprv.
	L12-Covering wall, window, or ceiling surface	3	5	3	4	5	4	1	5	–	5	1	5	5	5	5	5	5	–	5	5	3	5	–	5	–	5	5	4	97	Aprv.
	L13-Opening or closing operable curtain(s)	4	5	4	4	4	4	1	5	–	5	1	4	4	4	5	4	4	–	4	4	3	4	–	4	–	5	5	4	85	Aprv.
	L14-Opening or closing curtain (s) using remote	4	5	4	5	3	3	1	5	–	5	1	3	4	3	5	4	4	–	4	4	3	4	–	4	–	5	5	4	81	Aprv.
	L15-Opening or closing curtain (s) using feedback system	5	2	2	5	3	3	1	2	–	2	1	3	5	3	5	5	5	–	5	5	3	5	–	5	–	5	5	4	86	Aprv.
	L16-Opening or closing operable window(s)	5	4	4	5	4	4	1	4	–	4	1	4	5	4	5	5	5	–	5	5	3	5	–	5	–	5	5	4	94	Aprv.
	L17-Opening or closing window (s) using remote	3	3	3	5	5	5	1	3	–	3	1	5	5	5	5	5	5	–	5	5	3	5	–	5	–	5	5	4	96	Aprv.
	L18-Opening or closing window (s) using	2	3	2	3	5	3	1	1	–	1	1	5	4	4	4	4	4	–	4	4	3	4	–	4	–	4	4	4	74	Aprv.

Table 4 (*continued*)

Approach.	**Building users' adaptive behaviors in response to indoor conditions provided by energy efficient lighting systems**	**Validation session 1**							**Validation session 2**				**Validation session 3**										**Validation session 4**							**Cons. (%)**	**GGDM Consensus**
		Participant 1			Participant 2				Participant 3				Participant 4			Participant 5			Participant 6				Participant 7			Participant 8					
		WP	**WPr** =c-WP3	c-**WP**	**WP**	r-**WP**=c-WP4	c-**WP**	**SV**	**WP**	**WPr**=–	c-**WP**	**SV**	**WP**	**WPr**=c-WP7	c-**WP**	**WP**	**WPr**=WP7	c-**WP**	**WP**	**WPr**=c-WP7	c-**WP**	**SV**	**WP**	**WPr**=–	c-**WP**	**WP**	**WPr**=WP5	c-**WP**	**SV**		
	feedback system																														

Note. WP: Participant's Rate to the validation aspect, c-WP: conclusion of participant's rate to the validation aspect considered as min $\{WP_j, \ WPr_j\}$, WPr: participant introduced resouce Rate to the validation aspect, –: participant did not provide value, SV: CGD session value considered by the GGDM researcher, Aprv.: the validation aspect is approved based on GGDM consensus rate of more than 70% agreement, n-Aprv: the validation aspect is not approved based on GGDM consensus rate of not more than 70% agreement.

dissatisfied percentage is up to 30%. In Comfort category C of ISO 7730, (i.e. comfort requirement extends to [0.7, 0.7]), 16% of users are dissatisfied. Hence, the average thermal comfort calculated by aforementioned thermal comfort models makes some errors and bias in proper thermal comfort prediction, specially, in offices with number of staff.

The current challenge of building thermal comfort models is to estimate individual's satisfactions and preferences. For example, recently, Veselý n and Zeiler [151] proposed a new concept called 'Personalized Conditioning' which "aims to create a microclimate zone around a single workplace in contrast to the traditional HVAC techniques". Through personalized ventilation the fresh and clean air can be directly supplied for the targeted user. Veselý n and Zeiler [151] indicated that the personalized conditioning has two major advantages over the total volume HVAC systems: (1) enhanced air quality due to higher ventilation effectiveness, and (2) potential for cooling due to higher air velocity. They claim this system has potentials to reach up to 60% energy saving with lowered cooling set point and reduced air flow rate.

Regarding the association between thermal comfort and energy consumption, further study is needed in the area of environment [152,153], social, economic, cultural, and Post-Occupancy Evaluation (POE) of the office buildings. This research tried to investigate and identify the user satisfaction adaptive behaviors which can be added up to exiting models and standards. Applying these contribute to estimate and predict building thermal comfort requirements more precisely. The findings may specifically help to improve current sustainable building assessment tools and standards in response to lighting and cooling systems in energy efficient building. These tools can be promoted in benchmarking 'Capacity Office Building' on user satisfaction rating and measurement which may enhance energy programs.

It is obvious that 'study on user satisfaction adaptive behavior requirements' will enhance sustainability of building in terms of functionality, serviceability, adoptability, human comfort requirement, well-being, and risk reduction of investment and negative impact on the nature [19]. Focusing on the energy efficient building, user satisfaction evaluation has been traditionally considered in the operation and maintenance phase of building life cycle. However, literature review indicates that the current phenomenon of majority of building assessment tools is lack of focus on energy, environment, and/or economic aspects in the design phase of building life cycle. In this purpose, the current research established significantly the comprehensive list of user satisfaction adaptive behaviors for evaluation of energy efficient building in the 'Design' phase. The research findings aid to enhance buildings' sustainability assessment techniques. Indeed, such assessment will aid building design and construction teams to have a metric assessment on downstream requirement of the end-users' satisfaction

The comprehensive list of user-satisfaction adaptive behaviors output by this research can be applied for two main purposes. Firstly, it can be applied for ameliorating the current existing sustainable building assessment tools placed in Level 2 and/or Level 3 of the ATHENA [154] classification. Secondly, it can be used for future development of building design and decision support tools, and also, building assessment frameworks and systems. Furthermore, the list can be applied for each five classes of building assessment tools which were initiated by Sustainable Built Environment-iiSBE (2001) – IEA Annex 31[155] classification system. The classes that can use the list of user satisfaction adaptive behaviors are, energy modeling software; environmental life cycle analysis tools; environmental rating system; environmental design guideline or design checklist, and environmental labeling and certification.

13. Conclusion

In conclusion, the research proved that user satisfaction is an inter-connected criterion in compliance with other assessment criteria like energy efficiency in sustainable building assessment tools. Among diverse aspects of user satisfaction, 'user satisfaction from adaptive behavior' was the focal approach in inter-connection with other sources affecting energy consumption in buildings. The research resulted with a list of 36 user satisfaction adaptive behavior' relevant to cooling and lighting systems in energy efficient indoor environments which were investigated and validated through an expert input study.

The end-users of the output would be both professionals and practitioners. Professionals, including, architects, engineers, facility managers, building owners, consultants, authorities, contractor, and academic researchers may use the research output for their purposes regarding fulfilling the requirement of building sustainability accreditation.

Further research can be done in the future specially within two categories. First, Macro-scale studies which address upstream research parallel to the current study. The Macro-scale studies may focus on following approaches,

- Descriptive study on correlation between building performance criteria.
- Formulating correlation of building performance criteria.
- Developing a framework to assess correlation of building performance criteria

Secondly, micro-scale studies which address downstream research in more detail and in continuation of further development of the current study.

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